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HALL EFFECT OF THE NFL COMPOUND $YbRh_2Si_2$*

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$YbRh_2Si_2$ is a weak antiferromagnet with $T_N \approx 70$ mK, situated very close to an antiferromagnetic quantum critical point (QCP). Here, we present measurements of the initial Hall coefficient $R_H(T)$ on high-quality single-crystalline $YbRh_2Si_2$ in the temperature range 16 mK to 300 K. Above 120 K, $R_H(T)$ is, as the magnetic susceptibility, of Curie–Weiss type. This allows for the separation of R_H into a normal (R_0) and an anomalous contribution. Interestingly, the value obtained for R_0 is very close to the value R_H reaches at the lowest temperatures. This indicates that, at the lowest temperatures, R_H is dominated by R_0 and thus probes the charge-carrier concentration.

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1. Introduction

$YbRh_2Si_2$ is the only Yb based f-electron metal known to date showing non-Fermi-liquid (NFL) properties in the undoped system at ambient pressure [1,2]. In fact, $YbRh_2Si_2$ undergoes an antiferromagnetic (AF) transition at a temperature as low as $T_N \approx 70$ mK, pointing to $YbRh_2Si_2$ being very close to an AF quantum critical point (QCP) [2]. Stimulated by neutron scattering results on $CeCu_{5.9}Au_{0.1}$ [3], which contradicted the theoretical predictions of the spin-density-wave (SDW) scenario for the QCP [4, 5], recently 'local' scenarios for the QCP in heavy-fermion (HF) metals have been proposed [6,7]. Hall-effect measurements are suggested [6,7] as an adequate tool to distinguish between the conventional SDW-QCP scenario and these local ones. While in the SDW scenario the (normal) Hall coefficient is expected to vary smoothly when tuning the system through the QCP, in the

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local scenarios it may change discontinuously: In HF Fermi liquids, the localized spins ($4f$ holes in $YbRh_2Si_2$) contribute to the Fermi sea volume as electrons (or holes) [8, 9]. If the electron-spin composite quasiparticles break up at the QCP, then the Fermi sea volume in the AF phase would be distinctly smaller than in the paramagnetic phase. To test this prediction with Hall-effect measurements, one has to face the problem that in HF compounds the Hall coefficient is usually dominated in a wide temperature range by the anomalous contribution [10]. Thus, the first step has to be to identify the *normal* Hall coefficient R_0 in the Hall-effect data. This is the purpose of the present work. Then, in a second step, the system should be tuned through the QCP. This latter work is under progress, with the system $YbRh_2(Si_{1-x}Ge_x)_2$.

2. Results and discussion

The $YbRh_2Si_2$ single crystalline platelet investigated here was prepared as described previously [1]. In our Hall-effect measurements we applied the magnetic field parallel to the c axis, which is the hard magnetic direction. An ac current was applied in the tetragonal plane. The Hall voltage contacts were almost perpendicular to the direction of the current, thus leading to a small misalignment voltage only. At each temperature setting, the Hall voltage was obtained as the asymmetric contribution upon field reversal. In Fig. 1 we show the temperature dependence of the initial Hall coefficient $R_H(T)$ of $YbRh_2Si_2$ on a semi-log plot. It is negative at high temperatures, assumes a minimum at 105 K, changes sign at 32 K, has a knee-like anomaly at approximately 20 K, passes over a maximum at 0.8 K, and tends to saturate at the lowest temperatures. Except for the low-temperature anomaly with a maximum at 0.8 K, this temperature dependence is typical of HF

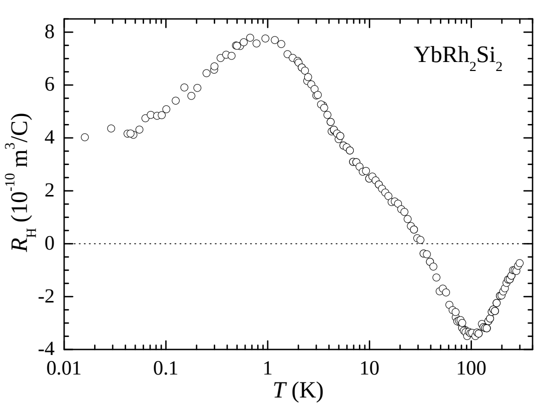

Fig. 1. Temperature dependence of the initial Hall coefficient R_H of $YbRh_2Si_2$.

systems [10]. A large anomaly with an extremum in the temperature range where the electrical resistivity ρ assumes a maximum (approximately 145 K for $YbRh_2Si_2$ with the current within the tetragonal plane [2]) is usually ascribed to the anomalous Hall effect due to skew scattering. While this anomaly is positive for most Ce-based HF systems, it may be expected to be negative for Yb-based systems [11]. At the lowest temperatures $R_H(T)$ tends to saturate in most HF systems [10]. For some systems the saturation value was interpreted as being dominated by skew scattering from residual defects [10]. Our analysis, however, indicates that in $YbRh_2Si_2$ the saturation value is dominated by the normal Hall coefficient, as will be outlined in the following. At temperatures above 120 K, $R_H(T)$ of $YbRh_2Si_2$ closely resembles the temperature dependence of the magnetic susceptibility $\chi(T)$ along the c axis which was shown to be Curie–Weiss like in this temperature range, with the paramagnetic Weiss temperature $\Theta \approx -180$ K and an effective moment close to the value for free Yb^{3+} [1]. This suggests the analysis of $R_H(T)$ in terms of the anomalous Hall effect, using the phenomenological expression $R_H(T) = R_0 + R_s \times \chi(T)$, with $\chi(T) = C/(T - \Theta)$ [11,12]. Here, $R_s \times \chi(T)$ is the anomalous contribution and C the Curie constant. Figure 2 shows that this relation holds above 120 K with temperature independent R_0 and R_s values. These values are 4.0×10^{-10} m^3/C and -3.4×10^{-10} m^3/C, respectively. Interestingly, the value of R_0 is in excellent agreement with the value to which R_H tends to saturate at the lowest temperatures (*cf.* Fig. 1). This strongly suggests that, at the lowest temperatures, the Hall coefficient is dominated by R_0 and thus probes the charge-carrier concentration. Between 15 and 80 K the relation $R_H(T) \propto \rho^2(T)$, predicted for the anomalous contribution below the peak temperature of $R_H(T)$ [11], is followed fairly

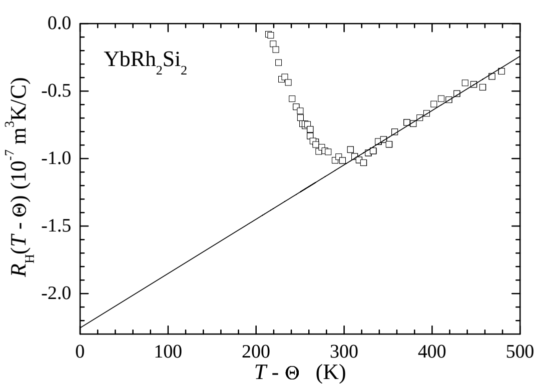

Fig. 2. Hall coefficient R_H multiplied by the difference of temperature T and paramagnetic Weiss temperature Θ *vs* $T - \Theta$. The linear behaviour above 120 K allows for the separation of R_H into a normal and an anomalous contribution.

well. The low-temperature anomaly with a maximum at 0.8 K cannot be understood in the simple interpretation scheme [10] for HF systems. We speculate that it may be related to $YbRh_2Si_2$ being close to a QCP.

3. Summary

The prime result of our Hall-effect measurements on $YbRh_2Si_2$ is that, at the lowest temperatures, the Hall coefficient is dominated by the normal contribution and thus monitors the charge-carrier concentration. This is a prerequisite for studying changes in the Fermi sea volume upon tuning the system through the quantum critical point.

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